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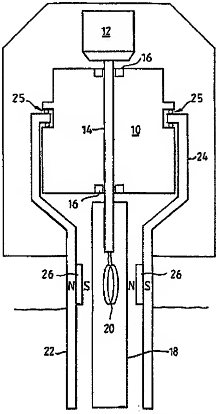
(54) Title: ROTATIONAL VISCOSITY MEASUREMENT

(57) Abstract

A rotational viscometer has an open ended outer cylinder (22) which is freely supported and a coaxial inner cylinder (18) which is rotated at one or more fixed angular velocities. Liquid in the annular region between the cylinders provides a viscous coupling causing the freely supported cylinder (22) to rotate. By providing a magnet (26) on one cylinder and an appropriately orientated coil (20) on the other cylinder, the voltage induced in the coil (20) provides a measure of relative rotation and thus of viscosity.



ROTATIONAL VISCOSITY MEASUREMENT

This invention relates to viscosity measurement and particularly to methods and apparatus for the measurement of liquid viscosity.

A wide variety of experimental techniques have been proposed for the measurement of liquid viscosity. However, there remains a commercial need for a viscosity measurement technique which offers high resolution at low viscosities, which can provide rapid results, on-line if necessary, and which is capable of embodiment in probe form for insertion into processing vessels and the like.

Conventional viscosity measurement techniques include flow measurements and a variety of techniques in which a body moves through the liquid whose viscosity is to be determined. Flow measurements become complicated if high resolution is required and are not generally capable of producing fast results. Moving body techniques include Stokes' falling body viscometer, and rotational viscometers. Falling body viscometers provide a high degree of resolution but generally cannot provide rapid measurements and cannot be embodied in probe form.

A well known form of rotational viscometer has a rotating cup containing a sample of the liquid whose viscosity is to be determined. An inner cylinder is mounted coaxially within the rotating cup on a torsion suspension. The torque applied to the inner cylinder through the viscosity of the liquid sample is measured as an angular deflection. In an alternative, it has been proposed that the functions of the inner and outer cylinders be reversed with the outer cylinder, containing the sample, being fixed and a constant torque applied to the inner cylinder by, for example, a pulley and weights. A measure of viscosity is then obtained from the angular velocity of the inner cylinder. In either approach, the end of the inner cylinder is often cone-shaped to reduce edge effects.

Rotational viscometers generally have the merit of simplicity and can produce rapid results. However, the known forms are not, generally, capable of providing high resolution at low viscosities, and are also not well suited to on-line measurements.

It is an object of this invention to provide improved methods and apparatus for determining the viscosity of a liquid which overcome some or all of the disadvantages of the known techniques discussed above.

Accordingly, the present invention consists, in one aspect, in a method of determining the viscosity of a liquid, comprising the steps of establishing a body of the liquid between respective opposing surfaces of a driven member and a freely supported passive member; continuously rotating the driven member so as, having regard to the spacing of said surfaces and the properties of the liquid, to effect a continuous rotation of the passive member; and measuring the rate of rotation of the passive member relative to the driven member to provide a measure of the viscosity of the liquid.

Advantageously, the rate of rotation of the passive member relative to the driven member is determined electromagnetically.

Suitably, magnetic field means and coil means are disposed one each on the passive member and the driven member respectively and the rate of relative rotation is determined through measurement of induced voltage in the coil.

In another aspect, the present invention consists in apparatus for determining the viscosity of a liquid, comprising a driven member; a freely supported passive member; means for establishing a body of the liquid between respective opposing surfaces of the driven member and the passive member; means for rotating the driven member and means for measuring the rate of rotation of the passive member relative to the driven member.

Preferably, the driven and passive members comprise respective coaxial cylinders, the outer of the two cylinders being open ended to enable insertion of the cylinders into the liquid whose viscosity is to be determined.

Advantageously, the driven and passive members are provided respectively with magnetic field means and coil means such that the voltage induced in the coil means is indicative of the rate of rotation of the passive member relative to the driven member.

This invention will now be described by way of example with reference to the accompanying drawing which is a somewhat schematic section through apparatus according to the present invention.

The illustrated viscometer comprises a bearing support 10, on the top of which is mounted a frequency controlled induction motor 12. The motor shaft 14 extends through the bearing support 10, rotating within bearings 16. The free end of the shaft 14 carries a cylindrical impeller 18. This may suitably be formed of PTFE. A pair of field coils 20 are embedded within the impeller with electrical connections (not shown) being taken through slip rings.

A hollow cylindrical driven member 22 extends coaxially over a major proportion of the length of the impeller 18. The upper region of the driven member 22 is formed as a bell-shaped housing 24 which is journalled on the bearing support member 10 at 25. Lightweight magnetic pole pieces 26 are mounted on the driven member 22 and may take the form of rubberised magnetic slugs. The magnetic pole pieces are positioned adjacent the field coils and above the maximum insertion depth of the viscometer.

In operation, the impeller 18 and surrounding driven member 22 are inserted as a probe into a body of the liquid whose viscosity is to be measured. Through close control of the motor 12, the impeller 18 is rotated at constant angular velocity. By virtue of the viscous coupling between the impeller 18 and the driven member 22, the latter begins to

rotate and, once equilibrium is established, rotates at a constant angular velocity. It is found that the difference in angular velocity between the impellor 20 and the driven member 22 is a reproduceable measure of the viscosity of the liquid. This difference in angular velocity is detected by means of the voltage induced in the field coils 20 as a result of the relative displacement between the magnetic field and the coils. It is well within the capability of one skilled in the art to produce circuitry which provides an output indicative of the relative angular velocity of the impellor and the driven member. Further description in this respect is therefore superfluous.

It is worth stressing that the relative velocity between the impellor and the driven member, and thus the output of the viscometer, is at a maximum when the viscous coupling is at a minimum. The viscometer according to this invention is therefore able to provide high resolution at low viscosities. This is in contrast to most techniques employed hitherto, where the measured signal decreases as viscosity decreases. A further important feature of the described viscometer is that measurements of viscosity can be made at differing velocities. Through the use of a suitedly programmed microprocessor (or manually if preferred) motor 12 can be controlled so as to pass through a range of different speeds, pausing at each speed for a sufficient time to allow equilibrium to be established and a measurement taken of the relative velocity between the impellor and the driven body. It will of course also be possible to arrange for repeated measurements to be taken at a single velocity so as to reduce random error.

It is necessary for the driven member to have a low moment of inertia and a bearing resistance which is as low as possible. The driven member may be formed of PTFE or thin section metallic tubing such as extruded aluminium.

It is recognised that the viscous coupling to the exterior of the driven member 22 from the surrounding body of liquid will represent an additional resistance to movement. However, this factor, being viscosity

related, does not reduce the resolution of the device. An alternative arrangement would have the external, hollow cylinder driven directly by the motor with the internal cylinder being freely supported. Under these circumstances, the viscous coupling to the surrounding body of liquid would not impose a drag upon the driven member.

Experimentally, better results have been achieved with the illustrated embodiment in which the internal cylinder is driven and the external cylinder floats. Whilst there is not yet a complete theoretical understanding of this phenomenon, it is believed that centrifugal effects produce more efficient viscous coupling when the inner member is driven rather than the outer.

The measurement of an induced voltage to provide an electromagnetic indication of relative velocity has the considerable advantage, mentioned above, that the signal is at a maximum at low viscosities. It will be understood that the position of the magnetic field means and the coil means can be interchanged without difficulty. The magnetic field means can take a variety of forms using permanent or electro magnets. The form and orientation of the coils can similarly be varied whilst maintaining the desired effect of an induced voltage which is a measure of relative velocity.

The geometry of the described device has the important advantage that the cylindrical driven member and cylindrical impeller form a probe which can be inserted into a body of liquid. The smooth and uncluttered surfaces of these parts leads to simple cleaning and sterilising procedures. If necessary, a seal can be provided between the impellor and the driven member, above the maximum immersion depth, to prevent liquid entering into the body of the viscometer. Although the probe geometry has many advantages, this invention will find application in other arrangements.

CLAIMS:-

1. A method of determining the viscosity of a liquid, comprising the steps of establishing a body of the liquid between respective opposing surfaces of a driven member and a freely supported passive member; continuously rotating the driven member so as, having regard to the spacing of said surfaces and the properties of the liquid, to effect a continuous rotation of the passive member; and measuring the rate of rotation of the passive member relative to the driven member to provide a measure of the viscosity of the liquid.

2. A method according to Claim 1, wherein the rate of rotation of the passive member relative to the driven member is determined electromagnetically.

3. A method according to Claim 1 or Claim 2, wherein magnetic field means and coil means are disposed one each on the passive member and the driven member respectively and the rate of relative rotation is determined through measurement of induced voltage in the coil.

4. Apparatus for determining the viscosity of a liquid, comprising a driven member; a freely supported passive member; means for establishing a body of the liquid between respective opposing surfaces of the driven member and the passive member; means for rotating the driven member and means for measuring the rate of rotation of the passive member relative to the driven member.

5. Apparatus according to Claim 4, wherein the driven and passive members comprise respective coaxial cylinders, the outer of the two cylinders being open ended to enable insertion of the cylinders into the liquid whose viscosity is to be determined.

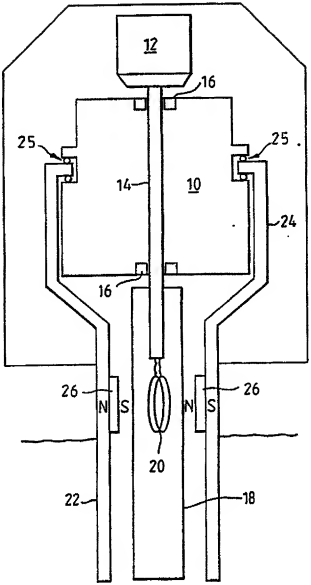
6. Apparatus according to Claim 4 or Claim 5, wherein the driven and passive members are provided respectively with magnetic field means and coil means such that the voltage induced in the coil means is indicative of the rate of rotation of the passive member relative to the driven member.

7. A viscosity measurement probe for insertion in a liquid whose viscosity is to be determined, comprising an outer cylinder which is open ended; an inner cylinder coaxially disposed within the outer cylinder; means for rotating one of the cylinders about the cylindrical axis; means providing for free rotation of the other cylinder and means for determining the relative rotation of the cylinders on viscous coupling of the cylinders through said liquid, the determined relative rotation providing a measure of viscosity.

8. A probe according to Claim 7, wherein said means for determining relative rotation comprises electromagnetic means having cooperating parts carried on the respective cylinders.

9. A method of determining the viscosity of a liquid comprising the steps of inserting into a body of the liquid a pair of coaxially disposed cylinders having respective opposing surfaces coupled viscously through the liquid, rotating a driven one of the cylinders and electromagnetically determining the rate of rotation of the other, passive cylinder relative to the driven cylinder.

10. A method according to Claim 10, comprising the steps of rotating the driven cylinder at a number of different angular velocities and determining the relative rate of rotation of the passive cylinder at each such angular velocity.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INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 91/00374

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: G 01 N 11/14

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	G 01 N

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	FR, A, 2587115 (VEGLIA.) 13 March 1987 see claims 1-2; page 2, lines 15-28; page 3, line 31 - page 4, line 24; page 8, lines 9-13 ---	1,4-5,7,9
A	EP, A, 0007427 (BROOKFIELD D.A.) 6 February 1980 see figure 4; page 7, line 20 - page 8, line 24 ---	1-3,6,8
A	FR, A, 843609 (FIDES) 6 July 1939 see page 2, lines 1-31; page 3, lines 2-44; resumé; figure 2 ---	1,4
A	US, A, 4062225 (R.J. MURPHY et al.) 13 December 1977 see abstract; figure 1	10

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
5th June 1991	10 JUL 1991
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	MISS T. TAZELAAR

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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9100374

SA 45820

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 26/06/91
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR-A- 2587115	13-03-87	DE-A- 3630565	12-03-87
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		JP-C- 1392836	11-08-87
		JP-A- 55004595	14-01-80
		JP-B- 61056775	04-12-86
FR-A- 843609		None	
US-A- 4062225	13-12-77	CA-A- 1079089	10-06-80
		DE-A,B 2736729	02-03-78
		GB-A- 1539993	07-02-79
		JP-A- 53026177	10-03-78

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